

## Appendix 2-C

### Travel Time Estimation

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#### 2.C.1 Introduction

Travel time ( $T_t$ ) is the time it takes water to travel from one location to another in a watershed.  $T_t$  is a component of time of concentration ( $T_c$ ), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed.  $T_c$  is computed by summing all the travel times for consecutive components of the drainage conveyance system.

Procedures and equations for calculating travel time and time of concentration are discussed in the following sections.

#### 2.C.2 Travel Time

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

Travel time is the ratio of flow length to flow velocity:

$$T_t = L/(3600V) \quad (2.C.1)$$

Where:

$T_t$	= travel time, hr
$L$	= flow length, ft
$V$	= average velocity, ft/s
3600	= conversion factor from sec to hrs

#### 2.C.3 Time Of Concentration

The time of concentration is the sum of  $T_t$  values for the various consecutive flow segments:

$$T_c = T_{t1} + T_{t2} + \dots T_{tm} \quad (2.C.2)$$

Where:

$T_c$	= time of concentration, hr
$m$	= number of flow segments

#### 2.C.4 Sheet Flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of watersheds. With sheet flow, the friction value (Manning's  $n$ ) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment. These  $n$  values are for very shallow flow depths of about 0.1 ft or so. Table 2-C-1 gives Manning's  $n$  values for sheet flow for various surface conditions.

Sheet flow conditions are unlikely for length in excess of 300 ft. In urban residential development, sheet flow conditions may occur in rear yards and other open areas but generally ease when flow occurs between buildings. For sheet flow use Manning's kinematic solution (Overton and Meadows 1976) to compute  $T_t$ :

$$T_t = [0.42 (nL)^{0.8} / (P_2)^{0.5} s^{0.4}] \quad (2.C.3)$$

Where:

$T_t$	= travel time, min
$n$	= Manning's roughness coefficient (Table 2-C-1)
$L$	= flow length, ft
$P_2$	= 2-year, 24-hr rainfall, in. (3.0 inches in Lincoln)
$s$	= slope of hydraulic grade line (land slope), ft/ft

**Table 2-C-1**  
**Roughness Coefficients (Manning's n) For Sheet Flow**

Surface Description	n <sup>1</sup>
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grasses:	
Short grass prairie	0.15
Dense grasses <sup>2</sup>	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods: <sup>3</sup>	
Light underbrush	0.40
Dense underbrush	0.80

<sup>1</sup> The n values are a composite of information compiled by Engman (1986).

<sup>2</sup> Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass and native grass mixtures.

<sup>3</sup> When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

This simplified form of the Manning's kinematic solution is based on the following:

1. shallow steady uniform flow,
2. constant intensity of rainfall excess (rain available for runoff),
3. rainfall duration of 24 hrs, and
4. minor effect of infiltration on travel time.

Another approach is to use the kinematic wave equation. For details on using this equation consult the publication by R. M. Regan, "A Nomograph Based on Kinematic Wave Theory for Determining Time of Concentration for Overland Flow," Report Number 44, Civil Engineering Department, University of Maryland at College Park, 1971.

### 2.C.5 Shallow Concentrated Flow

After a maximum of 300 ft, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from equations 2.C.4 and 2.C.5, in which average velocity is a function of watercourse slope and type of channel.

<b>Unpaved</b>	<b><math>V = 16.1345(s)^{0.5}</math></b>	<b>(2.C.4)</b>
<b>Paved</b>	<b><math>V = 20.3282(s)^{0.5}</math></b>	<b>(2.C.5)</b>

Where: V = average velocity, ft/s  
s = slope of hydraulic grade line (watercourse slope), ft/ft

These two equations are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and r (hydraulic radius, feet). For unpaved areas, n is 0.05 and r is 0.4 ft; for paved areas, n is 0.025 and r is 0.2 ft.

After determining average velocity, use equation 2.C.1 to estimate travel time for the shallow concentrated flow segment.

## 2.C.6 Open Channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Manning's equation is:

$$V = (1.49 r^{2/3} s^{1/2})/n \quad (2.C.6)$$

where:

V	= average velocity, ft/s
r	= hydraulic radius, ft (equal to $a/p_w$ )
a	= cross sectional flow area, ft <sup>2</sup>
$p_w$	= wetted perimeter, ft
s	= slope of the hydraulic grade line, ft/ft
n	= Manning's roughness coefficient

After average velocity is computed using equation 2.C.6,  $T_t$  for the channel segment can be estimated using equation 2.C.1.

## 2.C.7 Reservoir Or Lake

Sometimes it is necessary to compute a  $T_c$  for a watershed which has a relatively large body of water in the flow path. This travel time is normally very small and can be assumed as zero.

One must not overlook the fact that this does not account for the travel time involved with the passage of the inflow hydrograph through spillway storage and the reservoir or lake outlet. This time is generally much longer and is added to the travel time across the lake. The travel time through lake storage and its outlet can be determined by the storage routing procedures in Chapter 6.

## 2.C.8 Limitations

- Manning's kinematic solution should not be used for sheet flow longer than 300 ft. Equation 2.C.3 was developed for use with the four standard SCS rainfall intensity-duration relationships. (i.e., Type II)
- In watersheds with storm drains, carefully identify the appropriate hydraulic flow path to estimate  $T_c$ . Storm drains generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult Chapter 3 to determine average velocity in pipes for either pressure or nonpressure flow.
- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. Detailed storage routing procedures should be used to determine the outflow through the culvert.